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THE PRECONDITIONING TEST FOR FIRE-RESISTANT HYDRAULIC FLUIDS

N.K. Sarin and K.J. Mintz

Canadian Explosive Atmospheres Laboratory

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N.K. Sarin* and K.J. Mintz**
Canadian Explosive Atmospheres Laboratory

ABSTRACT

A pumping system has been developed to evaluate the change in fire-resistance of hydraulic fluids as a function of operating cycles. Thirteen fluids have been studied. Two synthetic fluids, a silicone and a phosphate ester, have shown definite increases in flammability, as measured by the spray-ignition test. Further work is required to determine if this increase in flammability can be correlated with a change in viscosity or some other physical measurement that can be made in the field. The 'preconditioning' test using this pumping system has already been incorporated into the Canadian Standard on Fire-Resistant Hydraulic Fluids (CSA M423-M84). It is recommended that the preconditioning test be applied only to synthetic fluids, rather than all fluids, as at present.

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*Investigation Officer at time of writing, **Research Scientist, Canadian Explosive Atmospheres Laboratory, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa.

ESSAIS DE PRÉ-CONDITIONNEMENT POUR LES LIQUIDES HYDRAULIQUES ININFLAMMABLES

N.K. Sarin* et K.J. Mintz**
Laboratoire canadien de recherche sur les atmosphères explosives

RÉSUMÉ

On a mis au point un système de pompage dans le but d'évaluer les changements de l'ininflammabilité des fluides hydrauliques en fonction des cycles de fonctionnement. Treize liquides ont donc été étudiés. Lors de ces études, deux liquides synthétiques, un silicone et un ester de phosphate ont démontré une nette augmentation de l'inflammabilité tel qu'indiqué par les résultats des essais d'allumage par pulvérisation. Il sera toutefois nécessaire d'entreprendre de plus amples travaux afin de déterminer si cette augmentation de l'inflammabilité peut être corrélée à un changement de viscosité ou à une autre évaluation physique qui peut être faite sur place. L'essai de pré-conditionnement effectué à l'aide de ce système de pompage a déjà été inclus dans les Normes canadiennes sur les liquides hydrauliques ininflammables (CSA M423-M84). Il est recommandé toutefois que l'essai de pré-conditionnement ne soit appliqué qu'aux liquides synthétiques et non à tous les liquides comme il se fait présentement.

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*Agent investigateur (lorsque ce rapport a été écrit), **Chercheur scientifique, Laboratoire canadien de recherche sur les atmosphères explosives, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa.

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INTRODUCTION

The hydraulic machinery used in mines requires large amounts of hydraulic fluids for transmission of power. In order to reduce the potential hazard of fires arising from the use of flammable hydraulic oils, the Canadian underground mining industry has converted in large part to fire-resistant hydraulic fluids (FRHF).

Over the past several years, the Canadian Explosive Atmospheres Laboratory (CEAL) has developed a facility for testing the fire-resistance of FRHF (1,2,3,4). CEAL has been certifying FRHF since 1978. The work carried out at CEAL played a major part in the development of the CSA Standard M423-M84.

Only fresh fluid was used for the flammability tests up to 1981. During a routine certification test in that year, it was noticed that a silicone-based FRHF did not atomize in the spray-ignition test. Although the ignition source would not ignite the solid jet of fluid emitted from the nozzle, the fact that the test could not be carried out properly required further investigation. The hot-channel test used by Factory Mutual Research (5) was attempted, but the results obtained were inconclusive. Then it was decided to precondition the fluid prior to subjecting it to the flammability test. The rationale was that the shearing action of a pump may degrade the fluid and allow atomization of the now shorter length polymer to occur. This, in fact, occurred when a sample was cycled through the ASTM D2882 wear test. Although the preconditioned fluid still passed the criteria of the spray-ignition test, it failed the wick flammability test. There arose the question whether other FRHF might also lose their fire-resistance while in use. This is the subject of the present report. Because of the potential hazard of such degradation in use, the CSA committee on Fire-resistant Hydraulic Fluids decided to include a fluid preconditioning test based on the preliminary results reported below on silicone fluid #1.

EQUIPMENT

The ASTM D2882 procedure was found to be very time-consuming for producing the necessary quantity of fluid required for the spray-ignition test. Moreover, the fact that moving parts of the apparatus used in D2882 are in contact with the test fluid makes the test one of compatibility as well as of wear. Therefore, a pumping system which does not require the fluid to be in contact with moving parts was constructed (Fig. 1). The main component of the system is the Pulsafeeder diaphragm metering pump, model 8480-E, in which a reciprocating pump generates the pumping action through an oscillating diaphragm. The volumetric output of the pump can be varied by an external manual adjustment of the piston stroke length. The output is independent of the viscosity of the test fluid.

The shearing action is achieved by passing the fluid through a spray nozzle (MONARCH-NS, 80° hollow cone rated at 1 GPM at 100 psi) while the system pressure is maintained at 3000 psi. The nozzle is mounted on top of the fluid reservoir through a quick disconnect coupling. The suction and bypass discharge lines are 3/8" s.s. tubes and the return is a flexible high pressure hydraulic hose 1/4" I.D. A 10 micron metal strainer is located inside the test fluid reservoir. Pulsations in the return line due to piston action are dampened by an accumulator charged with nitrogen at 1200 psi. A pressure regulator and pressure gauge are installed to allow system pressure adjustments while the pump is operating. Several drain connections are provided for flushing the system during oil changes. The entire assembly is mounted on castors.

A pressure transducer and a K type thermocouple are installed on the outlet end of the pump head assembly. Another thermocouple is installed in the test fluid reservoir. Outputs from these instruments are fed into a chart recorder for continuously monitoring the system's operation. A temperature controller in the fluid reservoir limits the test fluid temperature by automatically stopping the electric motor should the fluid in the reservoir exceed 65°C.

EXPERIMENTAL PROCEDURE

In order to ensure that the preconditioning system did not contain any traces of foreign material, i.e., fluid from previous tests, the system was flushed twice with 5L of the test fluid and the pump run each time for 15 minutes. The spray nozzle inside the reservoir was removed, cleaned and re-installed. Nine litres of fluid was then added to the reservoir.

With the pump running at its maximum volumetric displacement, and the return line blocked off, the system pressure was set to 3000 psi by manually adjusting the pressure regulating value on the bypass line. The return line valve was then opened to begin the preconditioning test. An alternative procedure would be to keep the bypass line closed and adjust the piston stroke of the Pulsafeeder pump to achieve the required 3000 psi. This procedure is now being investigated.

The flow rate through the spray nozzle was measured by collecting samples from the spray nozzle for periods of 30 s at a time. Although the pump volumetric displacement is independent of the fluid, the fraction of the fluid going through the spray nozzle depends on the viscosity of the fluid. (The flow of the fluids is approximately evenly split between the bypass line and the return line.) Approximately 150 h of pumping is required for the 500 cycles specified in the M423-84 Standard. At present, the pumping system requires an operator to monitor it and make adjustments to keep the pressure constant, as well as restart it after the temperature controller has turned off the pump when the temperature of the fluid exceeds 65°C. Automation of the apparatus would be desirable.

The spray-ignition tests were carried out following the procedures in the M423-84 standard. (The details of the apparatus and technique are described in Ref. 4.)

RESULTS AND DISCUSSION

Thirteen different hydraulic fluids, encompassing four different types, were conditioned in the Pulsafeeder pump system for various number of cycles and subsequently subjected to the spray-ignition test. The number of trials in each set of spray-ignition tests ranged from 4 to 26, depending on

the quantity of fluid available. The means and standard deviations of the burning times, together with the maximum values (shown in brackets) are shown in Table 1.

These tests were carried out between March 1983 and April 1985. During that time, it was learned that using a worn nozzle in the spray-ignition test may detrimentally affect the results. The replacement of the nozzle during the tests on "invert emulsion #1" renders meaningless the comparison between the 500 cycle test and the others.

The CSA Standard M423 sets the requirement for passing the spray-ignition test in terms of the maximum value (each of the 20 trials must have a burning time less that 30 s). The difficulty in using maximum values in comparing one data set with another is their large uncertainties due to random variations and the problem of applying valid statistical methods. Therefore, in this report, only the mean values will be used for determining if differences are significant or not.

The Geary statistical test (6) for deviations from the normal (Gaussian) curve was applied to each set of data. At the 95% confidence level, 7 of the 48 sets proved to not follow the normal distribution. The Geary test cannot prove that a given set of data follows the normal distribution, only that is is not inconsistent with normality. In other words, it is possible, that if more measurements were made, that some of the other data sets would also show deviations from normality.

Assuming normality, a statistical test (7) can be carried out to determine if the maximum value of each data set is an "outlier". Fourteen of the 48 sets were shown to contain an outlier (at the 95% confidence level), that is, that these come from a different "population" than the other values in that data set. Outliers are often interpreted physically as gross errors of measurement, but in this case, they are more likely due to the occurrence of a different physio-chemical phenomenon. It can be argued with some justification that the maximum values are indeed indicative of the most hazardous case and therefore should be used. On the other hand, if this high value occurs, say, on average once every 5 tests, there will be many sets of 10 tests done under the same conditions that will not have this outlier. A better approach, in the author's (K.M.) opinion would be, to increase either the severity of the test or the test criterion and use the mean value rather than the maximum.

Five data sets were repeated to give an indication of their reproducibility: the measurements were carried out several months apart. In only one did case the mean values differ by more than the experimental scatter. The maximum values were more scattered as should be expected. Hence, the evidence is that the mean values are reasonably reproducible.

The silicone fluids definitely increase in flammability (as measured by the spray-ignition test) after conditioning. This increase is probably caused by the degradation of the polymer, through the shearing action of the spray nozzle in the preconditioning system, resulting in a fluid which can atomize better when passed through the spray nozzle of the spray-ignition test. The question that remains unanswered at this time is if these silicone fluids can degrade sufficiently to fail the spray-ignition test. The relationship to the real-life situation also requires examination. The ASTM wear test does have merit in simulating more closely a mine hydraulic system. However there are practical difficulties associated with using it for certification testing. An alternative approach might be to correlate the change in viscosity of a given fluid with its performance in the spray-ignition test.

The phosphate ester fluid #1 apparently shows some indication of decreasing in flammability with increasing conditioning time. A one-way analysis of variance (ANOVA) on the data shows that the effect of conditioning time is significant at the 95% confidence level. However, the ANOVA calculation assumes that the standard deviations are approximately equal (8) which is not the case. In addition, the "run test for randomness" (9) applied to the 500 cycles spray-ignition test data indicates that (at the 95% confidence level) there was a trend to lower values during those tests for unknown reasons. Thus, the conclusion that the flammability of the phosphate ester HF decreases with time should be viewed with great caution.

In contrast to the phosphate ester #1, the phosphate ester #3 shows an increase in flammability with conditioning. The ANOVA calculation indicates that this conclusion is significant at the 99.9 + % confidence level. The reason for the different trend with phosphate ester #3 than with phosphate ester #1 is unknown. Hence, it would be safest to continue preconditioning the phosphate esters until more definitive results are available.

The water-glycol fluid shows an apparent increase in burning time with number of cycles. The ANOVA calculations indicate that this trend is not statistically significant.

The invert emulsion fluid #2 shows a trend to greater flammability with increasing number of cycles. This is statistically valid at the 99.9 + % confidence level, by the ANOVA method. With emulsions, the usual reason for an increase in flammability is a loss of water. At the time that these tests were carried out, the water content of the fluids was not measured. CEAL has recently installed a Karl-Fischer automatic titrator to determine water content of hydraulic fluids, which will enable us to determine if loss of water for emulsion #2 is the cause of the increase in flammability.

The invert emulsion #4 is of interest because it marginally fails the spray-ignition test. Its flammability does not change (within the experimental uncertainty) with the number of cycles.

The invert emulsion #5 shows a sharp increase in flammability between 500 and 750 cycles. Further work is required to identify its cause.

A quantitative, easily carried out test for the flammability of hydraulic fluids would be useful as a quality control tool in place of the spray-ignition and wick tests. One of us (N.S.) has begun work on the application of the critical oxygen index test (10) for this purpose.

CONCLUSIONS

1. The necessity for applying a preconditioning test to silicone hydraulic fluids and perhaps other synthetic fluids has been proven. On the other hand, the usefulness of the preconditioning test for emulsions and glycol solutions has not been proven. Therefore, it is recommended to use the preconditioning test only for synthetic types of hydraulic fluids.
2. The correlation of spray-ignition test results with change in viscosity (generated by various number of cycles) should be studied.
3. The spray-ignition test requires some modification of apparatus and procedures to improve its reliability.

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Table 1 - Burning time in the spray-ignition test as a function of cycles through the preconditioning pump system

	Mean burning time (s) [max. burning time in brackets]					
No. of cycles:	0	100	250	500	750-800	1000
Hydraulic fluid						
Silicone #1	0 [0]	1.0 ± 0.2 [1.4]	1.4 ± 0.6 [2.9]	7.0 ± 5.5 [18.5]	-	-
Silicone #2	0 [0]	- -	- -	1.8 ± 0.7 [3.7]	3.5 ± 1.3 [6.3]	-
Phosphate ester #1	16.4 ± 2.7 [19.7]	-	12.9 ± 2.8 [16.8]	11.0 ± 4.4 [16.0]	-	-
Phosphate ester #2	1.7 ± 0.9 [4.1]	-	5.1 ± 1.5 [7.0]	2.4 ± 0.9 [4.2]	-	-
Phosphate ester #3-Trial 1	4.9 ± 1.8 [8.0]	-	8.2 ± 3.1 [10.8]	10.3 ± 0.8 [11.5]	-	13.0 ± 3.3 [18.7]
Phosphate ester #3-Trial 2	-	-	9.8 ± 0.8 [11.0]	6.2 ± 1.8 [7.9]	-	16.5 ± 2.0 [18.5]
Phosphate ester #4-Trial 1	11.4 ± 3.5 [17.3]	-	-	12.8 ± 3.8 [19.2]	-	12.2 ± 1.2 [14.1]
Phosphate ester #4-Trial 2	-	-	-	9.6 ± 1.4 [11.4]	-	-
Water-glycol	0.6 ± 0.5 [1.2]	-	0.8 ± 0.4 [1.5]	1.2 ± 0.8 [3.7]	-	-
Invert emulsion #1	16.8 ± 4.8 [24.6]	-	23.2 ± 6.1 [28.0]	4.1 ± 4.0* [14.5]		
Invert emulsion #2	2.1 ± 1.4 [6.4]	-	3.0 ± 2.1 [7.7]	5.4 ± 2.3 [9.3]	-	-
Invert emulsion #3	1.4 ± 0.2 [1.9]	-	1.5 ± 0.7 [3.7]	1.6 ± 0.9 [5.3]	-	-
Invert emulsion #4	30.2 ± 6.4 [39.0]	-	26.1 ± 12.6 [33.0]	29.0 ± 4.7 [36.0]	-	-
Invert emulsion #5	2.2 ± 1.3 [5.4]	-	2.8 ± 2.6 [11.2]	3.0 ± 2.4 [7.2]	9.9 ± 2.1 [13.8]	-
Invert emulsion #6-Trial 1	10.3 ± 2.6 [13.4]	-	-	-	-	-
Invert emulsion #6-Trial 2	12.3 ± 4.4 [20.0]	-	9.4 ± 3.9 [14.0]	4.5 ± 3.2 [10.1]	9.2 ± 2.4 [14.0]	-

*Nozzle of spray-ignition test was changed from that used for the 0 and 250 cycles test

Note: Limits of error shown are standard deviations

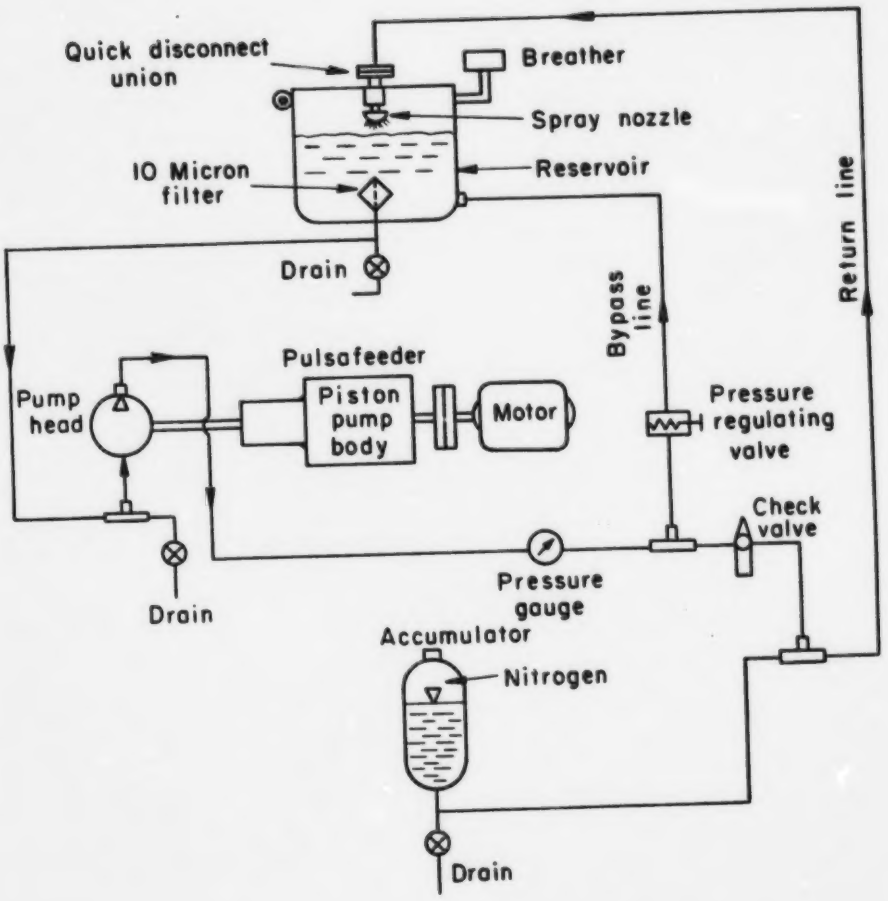

Fig. 1 - Hydraulic fluid preconditioning pump system